Open Journals of Environmental Research (OJER)
ISSN: 2734-2085
Article Details:
openjournalsnigeria.org.ng/pub/ojer20200202.pdf
Article Ref. No.: OJER20200202
Volume: 1; Issue: 2, Pages: 09-35 (2020)
Accepted Date: November 23, 2020
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Open Journals Nigeria (OJN)
Open Access | Bi-annual | Peer-reviewed
www.openjournalsnigeria.org.ng
editorial@openjournalsnigeria.org.ng

RESEARCH ARTICLE **OJER20200202**

PHYSICO-CHEMICAL CHARACTERISTICS OF TIN MINING POND WATER USED FOR IRRIGATION IN PLATEAU STATE, CENTRAL NIGERIA

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ABSTRACT

The present work was conducted by monitoring the water from twelve major tin mine ponds water in Plateau State, North Central Nigeria (Bokkos, Barkin – Ladi and Jos – South) used for irrigation. The quality was assessed in terms of physico-chemical parameters for dry and rainy seasons. Their physico-chemical parameters such as; Turbidity, pH, Temperature, Electrical Conductivity (EC), Cation Exchange Capacity (CEC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total alkalinity (TA), Total Hardness (TH), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Phosphate (PO_4^{3-}), Sulphate (SO_4^{2-}), Chloride (Cl^-), Fluoride (F^-), Sodium (Na^+) and Potassium (K^+) were investigated to ascertain the water quality for irrigation purposes. Water quality parameters with regards to its use for the purpose of irrigation such as FAO/WHO/FEPA standards satisfy the requirement for use in agriculture. However, turbidity which ranged from18.1 – 27.4 and 15.9 – 18.8, dissolved oxygen 20.9 – 26.3 and 20.2 – 27.4 mg/L, Total alkalinity 101 – 134 and 122 – 167mg/L, total phosphate 6.3 – 8.9 and 6.5 – 10.5 mg/L, BOD 7.4 – 23.8 and 7.2 – 29.2 mg/L, potassium 1.13 – 1.18 and 3.81 – 4.63 mg/L both in dry and rainy seasons, respectively were found to be above the irrigation water standard limits. The study therefore recommends that the mining pond water should be used with caution as some of the parameters are liable to be toxic to the irrigated crops. The positive correlation exhibited among some of the parameters examined is a clear indication of a common relationship between these sources of water.

Keywords: *contamination, irrigation, mining, ponds, Tin*

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INTRODUCTION

Water demand is remarkably increasing in many countries around the world for various reasons due to population expansion, economy's prosperity, and the improvement of living standards. One of the most demanding fields, however, is agriculture, since it makes use of 67% of total water withdrawal which represents 86% of water consumption in 2000 as reported (UNEP 2005). According to the Food and Agriculture Organization, 277 million hectares of lands are irrigated out of 1.4 billion hectares of arable ones, which provides one-third of the world's food production (Gurel *et al.,* 2007).

Irrigation with tin mining pond water provides an economic and cost-effective option for the scarcity of water in central part of Nigeria. Rapid population growth, increased urbanization, and a rising demand for drinking and irrigation water coupled with tightening regulatory restrictions on disposal of wastewater, all take the lead with discovery of Tin in 1903 and 1904 during the colonial era in which large mining ponds were dug in 1938 increasing use of tin mine pond water for irrigation in Plateau State (Mafuyai *et al.,* 2019a). The quality of irrigation water is a crucial factor for long term soil productivity. Poor quality water in conjunction with other inorganic/organic fertilizers for a long time in irrigation can make the soil less productive or even barren depending on the amount and type of substances present in the water (Bixio *et al.,* 2006). Many areas in Nigeria are facing a serious problem on both scarcity and quality of water (Gongden and Lohdip, 2015). The deterioration of water quality is associated with climate change and population growth. Hence, the quality of surface water is not only dependent on natural environmental processes such as weathering, erosion and precipitation, but also on the influence of anthropogenic activities including urbanization, agricultural activities and mining (Khatri and Tyagi, 2015).

Tin was first recognized in Nigeria in the early 1900s and dominated most of the production for over half a century. The expatriate exploration with drag line began in 1904 in Plateau State (Samuel *et al.,* 2015). The production of tin in Jos Plateau started with 1.5 metric tons in 1914 and reached peak production of 17.740 metric tons in 1943 when Nigeria became the 6th world producer (Patterson, 1986). However, the lack of proper environmental monitoring and enforcement during mining operations resulted to environmental degradation. This led to the creation of 10-40-meter-deep mine ponds filled with accumulated water (Balamurugan, 1991). The early tin mines were concentrated in North-Central Nigeria and consequently became one of the largest tin producers in Nigeria. The abundant ex-mining ponds in the early 1980s in with other local miners using hand dug wells in central Nigeria with large volumes of water have been suggested to support the daily water demand of the inhabitants of the areas (Low *et al.,* 2016; Koki *et al.,* 2017).

Various studies have been carried out to show the physico-chemical characteristics of wastewater which has direct and indirect impact on soil health and also the mobility of heavy metals from soil to vegetation. Some salient works in these aspects have been highlighted. Alghobar and Suresh, (2017) conducted a study on irrigation water sources (mines water, sewage water, treated sewage water, mixed water and ground water) and considered the following parameters; temperature, pH, EC, BOD, COD, TDS, Ca^{2+}, Na^{+}, K^{+}, Cl^{-}, PO_4^{3-} and SO_4^{2-} concentration. Roli (2014) analyzed sewage water used in the irrigation of suburb of Jamkhandi, Karnataka revealed that good amount of Zn, Cu and Mn enrichment in irrigation water and soil. The physico-chemical characteristics (pH, TDS, Cl^{-} alkalinity, total hardness, COD, NO_3^{-} and PO_4^{3-}) of Ayad river wastewater used for irrigation were suitable

(Bamniya *et al.,* 2010). The analyzed characteristics of wastewater used in the irrigation of agricultural fields of Durgapur (Gupta *et al.,* 2008). Parameters such as pH, EC, TSS, TDS, total hardness, Cl–, NO_3^-, PO_4^{3-}, SO_4^{2-}, COD and total Fe content in the irrigation water were considered. The comparative physico-chemical properties of drinking water and treated wastewater used for irrigation (Manas *et al.*, 2009) considered the following parameters; COD, BOD_5, TSS, pH, EC, TP, NO_3^-, SO_4^{2-}, Cl^-, Ca^{2+}, K^+. Physico-chemical characteristics of irrigation water used in Dinapur and Lohta sites located in suburban areas of Varanasi was identified to be suitable for irrigation with close monitoring (Singh *et al.,* 2009). Physico-chemical characteristics of raw effluent and open cast pit (OCP) water used for irrigation (Gupta *et al.,* 2010) and the physicochemical properties of the soil samples from study area, Bestari Jaya, Kuala Selangor, Peninsular Malaysia were analyzed (Muhammad *et al.,* 2010).

There is a global concern on the quality of surface water for consideration as source of supply for agricultural purpose, human consumption and other domestic needs (Kazi *et al.,* 2009). The environmental status of tin mined ponds is dependent on the type of the pond and its exposure to various environmental factors. The shortage of water for daily human and domestic activities especially in the period of dry season has prompted the search for other sources of water supply. Based on the water crisis faced by local farmers to enhance their crop production in Plateau State, holistic approach is needed to address it decisively. It is therefore, imperative to determine the physico-chemical parameters of the mining pond water to ascertain their suitability for irrigation purpose.

MATERIALS AND METHODS

STUDY AREA

The study areas lie between latitude 9°18’N to 9°54’N and longitude 8°50’E to 8°59’E and this cover an area of about 3224 km^2 in terms of land mass. According to National Population Commission (NPC, 2006), the studied area has an estimated population of 671,157. The study area is a hosts to a lot of mining activities by foreign companies such British Mines Corporation Limited, Bisichi Jenta Limited, Gold and Base Corporation, Exland and Kaduna Prospectors (Kazi *et al.,* 2009). The map of the studied Local Government Areas; Jos – South, Barkin- Ladi and Bokkos as shown in (Figure 1a, b and c) with the sampling ponds labeled.

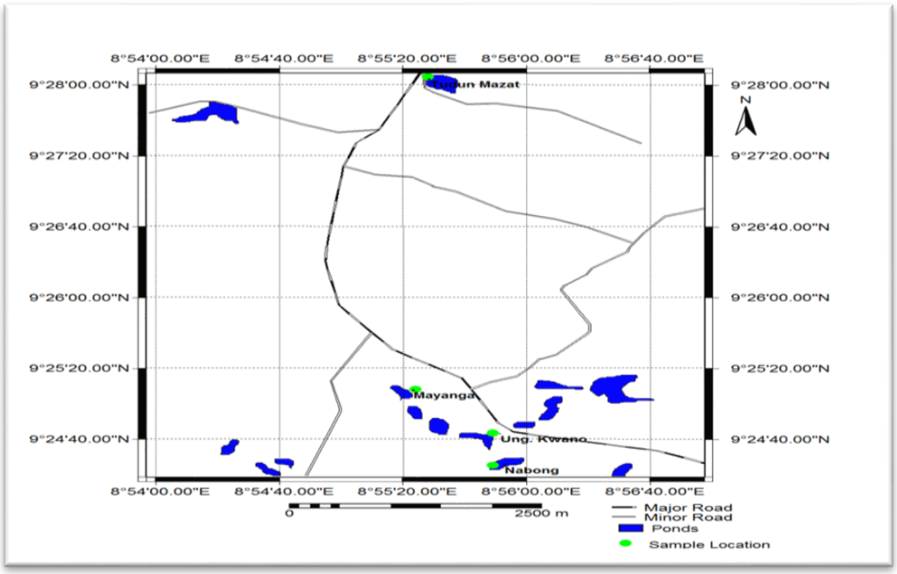

Figure 1a: Map of Jos – South showing sampling ponds

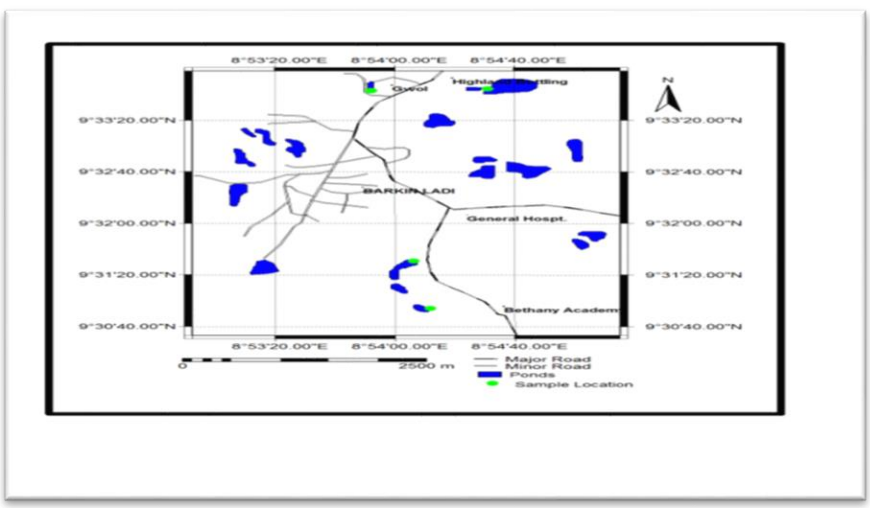

Figure 1b: Map of Barkin – Ladi showing sampling ponds

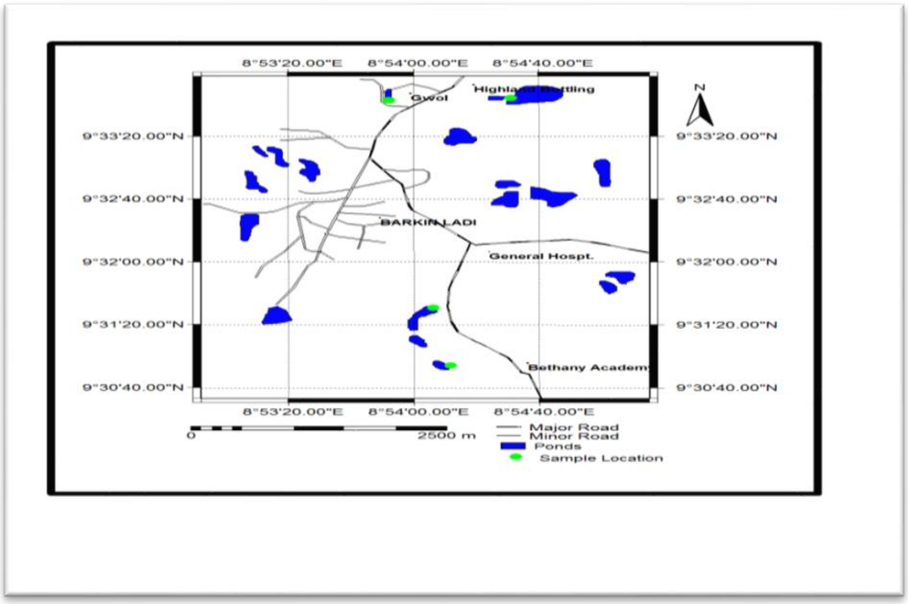

Figure 1c: Map of Bokkos showing sampling ponds

These companies rendered the areas derelict with numerous waste dumps and ponds. The impact of the past mining activities on the landscape is devastating as several tin mined-out pits ranging from 10 m to about 40 m in depth were left with various hazardous effects (Figure 2a, b). These tin mined-out pits which are filled with water are generally referred to as Mine Ponds Water (Figure 3a, b, c). The people of these areas are predominantly farmers and use the mine ponds to irrigate crops such; potatoes, tomato, pepper, cabbage, carrot, spinach, garden egg and many other varieties of crops (Mafuyai *et al.,* 2020).

(a) (b)

Figure 2: Some derelict areas (a) deep pond (b) mined dump (Cutesy G. M. Mafuyai, 2020)

SAMPLING AND PRESERVATION

The samples of water were collected from the study areas using standard analytical methods (APHA, 1998; FAO,1985). A total of twelve (12) major tin mining ponds, four (4) from each Local Government Areas studied and Global Position System (GPS) of each sampling station documented. At each sampling point, the pitcher was lowered completely into the water at about 20 cm to obtain desired volume; samples were immediately placed in ice boxes after taking the temperature and pH and transported to the laboratory for analysis. In each of the pond four areas were located and the sampling done in triplicate from each of the site identified in the pond. The same sampling points were used and 1L of water was collected from both the identified sites in wet and dry seasons from the mining ponds, totaling 96 samples in the two seasons.

(a)

(b)

(c)

Figure 3: Tin mining pond used for irrigation in (a) Bokkos, (b) Barkin-Ladi (c) Jos- South. (Cutesy G. M. Mafuyai, 2020)

The water samples were obtained in 2018 and 2019 during the dry seasons (March) and rainy seasons (August) from each of the ponds and analyzed for water quality parameters (temperature, turbidity, pH, electrical conductivity, total alkalinity, TDS, TSS, COD, BOD, DO, PO_4^{3-}, SO_4^{2-}, Cl^-, Na^+, K^+) using standard methods of examination of water as shown in the table below.

Table 1: Summary of Analytical Procedures used for the Analysis

Parameters	Procedure	Reference
Turbidity	Nephelometer	APHA 1998
Temperature	Thermometer	APHA 1999
pH	pH Meter	APHA 2000
EC	Conductivity meter	Saxena 1998
TSS	weight difference using Drying Oven	APHA 2002
TDS	weight difference using Drying Oven	APHA 2003
BOD	Titrimetry	APHA 2004
COD	Titrimetry	APHA 2005
DO	Titrimetry	APHA 2006
TA	Titrimetry	Saxena 1998
TH	Titrimetry	APHA 2008
Cl^-	Titrimetry	APHA 2009
NO_3^-	Spectrophotometry	APHA 2010
SO_4^{2-}	Spectrophotometry	APHA 2011
TPO_4^{3-}	Spectrophotometry	APHA 2012
F^-	Ion selective electrode	APHA 2013
NH_4^+	Spectrophotometry	APHA 2014
Na^+	flame photometry	Black 1965
K^+	flame photometry.	Black 1965

CONTROL AND QUALITY ASSURANCE

Analytical grade reagents and distilled deionized water were used throughout the study. Precision and accuracy of analyses was ensured through replicate analyses by carrying experiment on each of sample three times using standard analytical procedures.

KARL PEARSON'S COEFFICIENT OF CORRELATION

Coefficient of correlation (r) is a quantitative measure of the correlation between two variables. The correlation coefficient measure correlation based on arithmetic mean and standard deviation. This method can be used to measure correlation for individual series as well as for grouped data.

$$r = \sum \frac{(\overline{X} - X)(\overline{Y} - Y)}{nSxSy}$$

where, r = coefficient of correlation, X = variable X, $\bar{X}$ = mean of variable X, Y = variable Y, $\bar{Y}$ = mean of variable Y, n = number of pairs of variables, S*x*= SD of variable X, and S*y* = SD of variable Y.
Statistical analysis of data was carried out using Microsoft Office Excel 2010 and the SPSS 16.0 statistical package programs.

STUDENT T – TEST

This test was used for testing the significance of difference between the means of two different samples of small size. It can be calculated using the following formula:

$$t = \sqrt[d]{SDd}$$

where, $\bar{d}$ = the mean of the difference between the paired values, SDd = standard deviation of the difference.

RESULTS AND DISCUSSION

RESULTS

The mean and standard deviation of the results of physico-chemical parameters for Bokkos, Barkin - Ladi and Jos - South Plateau Central Nigeria, are all presented in Tables 2, respectively. The FAO/WHO standards are also presented along with the physico-chemical parameters. The Pearson's correlation coefficient matrix between the parameters that were determined in both seasons in each study area are presented in Tables 3, 4, 5, 6, 7, 8,). The mean turbidity of the mining pond water in dry and rainy seasons ranged from 18.1 – 27.4 and 15.9 – 18.8 NTU, respectively. In this study, the turbidity in dry season were highest in Barkin - Ladi 27.4±1.2 with the lowest in the rainy season in Bokkos 15.9±0.6. The high turbidity in dry season is connected with wind action during the period blows a lot of debris into the ponds due to inadequate soil cover, these result in low oxygen and sunlight penetration for aquatic species. The mean temperature of the mining pond water in dry and rainy seasons ranged between 23.8 – 25.1 ^{0}C and 28.5 – 29.3 ^{0}C, respectively. The highest temperature in dry and rainy seasons was in Jos – South 25.1 ^{0}C and 29.3 ^{0}C respectively.

The mean pH of the mining pond water used in irrigation ranged from 6.38 – 6.73 during dry season, while that of rainy season was slightly higher than that of dry season, with a range of 6.4 - 6.8. The mean pH values recorded in all sampling sites were within the FAO/WHO, (2007) permissible limits of 6.5 – 8.5. The mean electrical conductivity (EC) values of mining pond water in the study sites range from 109 – 220 µS cm^{-1} in dry season, while in rainy season the range were 123 - 128 μScm^{-1}. The mean concentration of TSS in the tin mining pond water used in irrigation of vegetables in dry – and - rainy season were in range of 520 – 718 and 10.4 – 123 mg/L, respectively.

The mean values of BOD in the tin mine pond water used in irrigation during dry season in the three sites were 7.37 - 23.8 mg/L, while the mean concentration in rainy season was 7.17 - 29.2 mg/L. The mean COD (mg/L) in the tin mine pond water in the sites studied during dry season were in the range of 22.0 – 36.0mg/L and 21.2 - 41.6±2.4 mg/L in rainy season.

The mean DO of mining pond water sample in dry - and - rainy season of the study sites were obtained in the range of 2.3 – 2.9 mg/L and 2.2 – 2.7mg/L, respectively. The highest DO was obtained in Jos – South in rainy season and lowest at Bokkos in both seasons. The DO in the studied mining pond water reported in this work was lower compared to the DO 6.88 mg/L and 6.90 mg/L (Bharose *et al.*, 2013) and (Alghobar and Suresh, 2017), respectively on wastewater used in irrigation.

The mean alkalinity of the tin mining pond water in the study areas were 101 – 134 mg/L in dry season and 122 - 167 mg/L as the range obtained in rainy season. The highest value was found in Jos – South in both seasons with the lowest obtained in Bokkos and Barkin – Ladi in dry – and - rainy seasons respectively. The value of alkalinity obtained in this work is higher compared to the reported value range 0.8 – 28.3 mg/L in Wase mining site Plateau state (Lawal *et al.*, 2014). The mean total hardness of tin mine pond water shows hardness range of 157 – 331 and 139 – 258 mg/L in dry – and – rainy seasons, respectively. The highest value was obtained in Barkin – Ladi in dry season with the lowest in Jos – South during rainy season.

The mean Cl^- concentration in dry season of the tin mine pond water were in the range 67.8 - 90.1 mg/L and 53.0 – 61.7 mg/L in rainy season. All mean values obtained from the tin mine pond water of dry season shows values higher than those obtained during rainy seasons. This may be due to evaporation of mining wastewater and high mining activities during the season. The mean NO_3^-–N concentration in tin mine pond water in the study sites were in the range 7.56 – 11.2 and 7.84 - 8.74±0.3 mg/L in dry – and - rainy seasons, respectively. The highest values in this work was obtain in dry – and - rainy seasons both in Barkin – Ladi and lowest in Jos – South. Though these values are lower compared to the findings of 13.08 mg/L reported in Barkin Ladi (Daniel *et al.*, 2014) and 19.51 mg/L (El-Arby and Elbolrdiny, 2006). The mean concentration of SO_4^{2-} in tin mine pond water used for irrigation were in the range 11.2 – 35. 2 mg/L, while the concentration range in rainy was 9.86 – 34.6 mg/L with the highest concentration found Jos – South in both seasons. The concentration in NH_4^+ tin mine water pond obtained range from 29.5 – 35.4 and 7.82 -11.0 mg/L in dry and rainy seasons, respectively. The highest concentration of ammonia in the tin mine pond water was found in Barkin – Ladi, in both seasons. The values in rainy season were observed to be almost similar during the season.

In dry season, the mean values of phosphate tin mine pond water ranged from 6.30 – 8.88 mg/L and 6.52 - 10.5±0.5 mg/L in rainy season quite higher than dry season, with highest and lowest concentration obtained in Bokkos. The values of phosphate in the tin mine pond water are quite higher than the values used in the irrigation of agricultural fields of Durgapur (Robinson, 2012) and lower compared to reported values in Ishiagu (Nukpezah *et al.*, 2017). The mean value of F^- in tin mine pond water in dry and rainy season were in the range 0.0 – 0.09 and 0.0 - 0.21 mg/L, similar concentrations were found in Barkin - Ladi and Jos – South.

There was no much observable seasonal variation in the concentration of Na^+ in the tin mining pond water during dry - and - rainy seasons with recorded mean values 13.3 – 14.6 and 13.1 - 15.8, respectively. In Bokkos the mean value recorded in the two seasons were 1.13 - 1.53 and 3.81 – 4.63 mg/L for dry – and - rainy seasons, respectively. The results of the rainy season were almost similar, the highest was recorded in Barkin – Ladi

Table 2: Mean ±SD Values of the Physico-chemical Parameters of Mining Pond Water in Plateau, North Central Nigeria

	Dry			Rainy			FAO/ WHO Standards
Parameters	**Bokkos**	**Barkin – Ladi**	**Jos**	**Bokkos**	**Barkin – Ladi**	**Jos**	
Turbidity	22.4±2.2	27.4 ±1.2	18.1 ±3.4	15.9±0.63	16.6 ±1.1	18.8 ±2.8	5
Temperature	23.8±0.56	24.9 ±0.49	25.1 ±0.32	29.9±1.2	28.5 ±1.3	29.3 ±0.73	30
pH	6.38±0.29	6.67 ±0.30	6.73 ±0.29	6.48±0.33	6.69 ±0.42	6.76 ±0.24	6.5 – 8.5
EC	117±1.5	109 ±1.8	220 ±7.3	183±1.2	128 ±2.2	210 ±8.5	750
TSS	640±10	718 ±6.2	520 ±17	29.0±1.5	10.4 ±0.65	123 ±4.4	100
TDS	254±11	288 ±7.9	219 ±2.4	281±6.1	414±5.5	267 ±4.5	500
BOD	7.37±0.90	9.58 ± 0.43	23.8 ±1.2	7.17±0.23	9.16 ± 0.33	29.2 ± 0.97	2
COD	22.0±1.2	25.3 ±0.76	36.0 ±0.88	21.2±1.1	22.0 ±0.32	41.6 ±2.4	350
DO	2.9±1.0	2.2 ±1.5	2.3 ±0.68	2.2±0.73	2.7 ±0.85	2.2 ±0.73	5
TA	101±1.3	127 ±8.1	134 ±4.8	134±1.3	122 ±1.5	167 ±1.30	100
TH	303±1.9	331 ±0.82	157 ±5.8	258±2.5	254 ±4.8	139 ±1.7	500
Cl^-	90.1±2.3	88.2 ±1.6	67.8 ±2.2	55.0±1.4	61.7 ±0.91	53.0 ±0.92	250
NO_3^-	9.20±0.77	11.2 ±0.35	7.56 ±0.43	7.84±0.38	8.74 ±0.31	8.41 ±0.39	50
SO_4^{2-}	11.7±0.75	7.56 ±0.57	35.2 ±0.54	11.7±0.31	9.86 ±0.46	34.6 ±1.1	500
TPO_4^{3-}	6.30±0.86	8.08 ±0.32	8.88 ±0.93	10.5±0.46	7.24 ±0.29	6.52 ±0.78	5
F^-	0.09±0.02	0.09 ±0.02	0.09 ±0.02	0.21±0.02	0.21±0.03	0.21±0.03	1.5
NH_4^+	29.5±0.57	35.4 ± 0.68	31.6 ± 1.2	11.0±0.57	10.8 ±0.27	7.82 ± 1.3	50
Na^+	13.6±0.89	13.3 ±1.1	14.6 ±1.5	13.1±1.5	15.8 ±1.1	14.5 ±1.4	200
K^+	1.53 ±0.1	1.13 ± 0.03	1.58± 0.12	3.81±0.2	4.63 ±0.27	4.14± 0.07	0.2

All parameters are in mg/L exception of Turbidity (NTU) temperature (^0C) pH and EC (µS/cm)

Table 3: Pearson's Correlation Coefficient Matrix of Physicochemical Parameters (Mean) of Old Tin Mining Pond Water Bokkos Dry Season

	Tub.	Temp	BOD	COD	DO	pH	EC	TSS	TA	TH	Cl^-	NO_3^-	SO_4^{2-}	TPO_4^-	F^-	NH_4^+	Na^+	K^+
Tub.	1.000																	
Temp	0.503	1.000																
BOD	0.184	0.572	1.000															
COD	0.432	0.526	0.950	1.000														
DO	-0.407	-0.152	-0.781	-0.909	1.000													
pH	0.018	0.836	0.769	0.590	-0.214	1.000												
EC	-0.462	0.445	0.013	-0.263	0.614	0.621	1.000											
TSS	0.953	0.651	0.472	0.672	-0.585	0.273	-0.380	1.000										
TA	0.343	-0.047	-0.811	-0.691	0.669	-0.499	0.018	0.069	1.000									
TH	0.977	0.583	0.087	0.305	-0.220	0.065	-0.290	0.909	0.477	1.000								
Cl^-	-0.306	-0.927	-0.817	-0.722	0.367	-0.956	-0.424	-0.544	0.417	-0.334	1.000							
NO_3^-	0.782	0.191	0.483	0.733	-0.859	-0.042	-0.784	0.831	-0.195	0.630	-0.218	1.000						
SO_4^{2-}	0.537	-0.225	0.481	0.666	-0.916	-0.188	-0.852	0.416	-0.519	0.121	0.035	0.844	1.000					
TPO_4^-	0.332	-0.419	0.505	0.497	-0.703	-0.026	-0.452	-0.165	-0.850	-0.519	0.071	0.332	0.767	1.000				
F^-	0.412	0.757	0.958	0.946	-0.724	0.805	0.037	0.668	-0.610	0.348	-0.908	0.551	0.388	0.264	1.000			
NH_4^+	-0.132	0.735	0.206	-0.016	0.429	0.783	0.933	-0.022	0.036	0.036	-0.675	-0.522	-0.754	-0.544	0.307	1.000		
Na^+	-0.914	-0.585	-0.557	-0.761	0.709	-0.265	0.466	-0.987	0.067	-0.837	0.533	-0.900	-0.551	0.001	-0.717	0.118	1.000	
K^+	0.172	-0.605	0.056	0.265	-0.643	-0.595	-0.945	0.137	-0.259	-0.026	0.475	0.654	0.896	0.696	-0.062	-0.966	-0.259	1.000

All parameters are in mg/L with the exception of Turbidity (NTU) temperature (^0C), pH and EC (µS/cm)

Table 4: Pearson's Correlation Coefficient Matrix of Physicochemical Parameters (Mean) of Old Tin Mining Pond Water Bokkos Rainy Season

	Tub.	Temp	BOD	COD	DO	pH	EC	TSS	TA	TH	Cl^-	NO_3^-	SO_4^{2-}	TPO_4^{3-}	F^-	NH_4^+	Na^+	K^+
Tub.	1.000																	
Temp	-0.914	1.000																
BOD	-0.608	0.842	1.000															
COD	0.812	-0.977	-0.932	1.000														
DO	0.851	-0.950	-0.930	0.963	1.000													
pH	0.224	-0.190	-0.467	0.246	0.477	1.000												
EC	-0.288	0.126	-0.389	0.038	0.176	0.797	1.000											
TSS	-0.918	0.680	0.306	-0.525	-0.635	-0.282	0.337	1.000										
TA	0.182	-0.528	-0.891	0.698	0.663	0.417	0.621	0.154	1.000									
TH	-0.125	-0.144	-0.649	0.331	0.399	0.692	0.933	0.314	0.861	1.000								
Cl^-	0.700	-0.388	-0.118	0.241	0.442	0.523	-0.092	-0.908	-0.277	-0.212	1.000							
NO_3^-	0.361	0.045	0.375	-0.226	-0.038	0.258	-0.279	-0.701	-0.691	-0.516	0.876	1.000						
SO_4^{2-}	0.174	-0.259	-0.627	0.366	0.548	0.959	0.888	-0.125	0.649	0.861	0.306	-0.021	1.000					
TPO_4^{3-}	0.553	-0.198	0.068	0.043	0.258	0.493	-0.096	-0.826	-0.424	-0.280	0.980	0.947	0.246	1.000				
F^-	0.607	-0.266	0.002	0.113	0.324	0.507	-0.094	-0.858	-0.373	-0.256	0.992	0.926	0.270	0.998	1.000			
NH_4^+	-0.371	-0.036	-0.461	0.240	0.107	-0.021	0.503	0.696	0.795	0.706	-0.798	-0.970	0.255	-0.869	-0.847	1.000		
Na^+	0.388	-0.073	0.474	-0.137	-0.153	-0.483	-0.890	-0.587	-0.800	-0.952	0.485	0.686	-0.684	0.522	0.510	-0.841	1.000	
K^+	-0.767	0.926	0.740	-0.915	-0.789	0.161	0.323	0.467	-0.499	-0.011	-0.079	0.282	0.037	0.108	0.043	-0.197	-0.110	1.000

All parameters are in mg/L with the exception of Turbidity (NTU) temperature (^0C), pH and EC (µS/cm)

Table 5: Pearson's Correlation Coefficient Matrix of Physicochemical Parameters (Mean) of Old Tin Mine Pond Water Barkin- Ladi Dry Season

	Tub.	Temp	BOD	COD	DO	pH	EC	TSS	TA	TH	Cl^-	NO_3^-	SO_4^{2-}	TPO_4^{3-}	F^-	NH_4^+	Na^+	K^+
Tub.	1.000																	
Temp	0.431	1.000																
BOD	0.685	-0.347	1.000															
COD	-0.383	0.263	-0.723	1.000														
DO	0.327	-0.705	0.873	-0.474	1.000													
pH	0.698	-0.225	0.828	-0.213	0.824	1.000												
EC	0.727	0.244	0.659	-0.856	0.228	0.269	1.000											
TSS	0.200	0.640	-0.182	-0.391	-0.602	-0.536	0.618	1.000										
TA	-0.886	-0.664	-0.438	0.463	0.044	-0.294	-0.854	-0.630	1.000									
TH	-0.649	-0.179	-0.407	-0.296	-0.407	-0.831	0.032	0.513	0.282	1.000								
Cl^-	0.067	0.696	-0.585	0.856	-0.591	-0.106	-0.465	-0.043	-0.060	-0.465	1.000							
NO_3^-	0.100	0.436	-0.103	-0.541	-0.483	-0.557	0.649	0.970	-0.531	0.657	-0.270	1.000						
SO_4^{2-}	0.518	-0.124	0.748	-0.986	0.439	0.269	0.927	0.449	-0.601	0.195	-0.762	0.567	1.000					
TPO_4^{3-}	-0.492	-0.388	-0.067	-0.577	-0.080	-0.583	0.235	0.429	0.206	0.936	-0.745	0.625	0.467	1.000				
F^-	-0.404	-0.543	0.142	-0.688	0.153	-0.384	0.295	0.292	0.205	0.832	-0.877	0.513	0.573	0.973	1.000			
NH_4^+	-0.664	0.055	-0.824	0.945	-0.494	-0.415	-0.952	-0.393	0.692	-0.012	0.667	-0.479	-0.982	-0.294	-0.414	1.000		
Na^+	0.892	0.437	0.639	-0.669	0.183	0.402	0.950	0.557	-0.962	-0.235	-0.198	0.516	0.782	-0.070	-0.017	-0.859	1.000	
K^+	0.323	0.508	-0.203	0.747	-0.175	0.342	-0.379	-0.336	-0.120	-0.806	0.895	-0.554	-0.642	-0.963	-0.996	0.491	-0.072	1.000

All parameters are in mg/L with the exception of Turbidity (NTU) temperature (^0C), pH and EC (µS/cm)

Table 6: Pearson's Correlation Coefficient Matrix of Physicochemical Parameters (Mean) of Old Tin Mine Pond Water Barkin- Ladi Rainy Season

	Tub.	Temp	BOD	COD	DO	Ph	EC	TSS	TA	TH	Cl^-	NO_3^-	SO_4^{2-}	TPO_4^{3-}	F^-	NH_4^+	Na^+	K^+
Tub.	1.000																	
Temp	0.040	1.000																
BOD	-0.173	0.254	1.000															
COD	0.939	-0.010	-0.499	1.000														
DO	0.416	0.925	0.191	0.339	1.000													
pH	0.050	0.990	0.384	-0.047	0.923	1.000												
EC	-0.628	0.577	0.734	-0.786	0.299	0.633	1.000											
TSS	0.919	-0.357	-0.264	0.882	0.025	-0.343	-0.815	1.000										
TA	-0.574	-0.198	0.813	-0.803	-0.377	-0.089	0.649	-0.094	1.000									
TH	-0.658	0.726	0.352	-0.667	0.411	0.717	0.887	-0.901	0.280	1.000								
Cl^-	0.917	0.247	0.218	0.735	0.582	0.302	-0.282	0.759	-0.292	-0.430	1.000							
NO_3^-	0.924	0.207	-0.440	0.976	0.531	0.167	-0.646	0.783	-0.833	-0.494	0.768	1.000						
SO_4^{2-}	-0.290	0.857	0.659	-0.450	0.680	0.901	0.903	-0.609	0.335	0.861	0.054	-0.257	1.000					
TPO_4^{3-}	-0.642	-0.268	-0.643	-0.343	-0.507	-0.375	-0.102	-0.493	-0.171	0.208	-0.886	-0.386	-0.317	1.000				
F^-	-0.412	-0.719	0.438	-0.552	-0.795	-0.634	0.122	-0.103	0.824	-0.233	-0.330	-0.698	-0.259	0.013	1.000			
NH_4^+	-0.422	0.785	0.683	-0.577	0.565	0.832	0.956	-0.704	0.439	0.899	-0.074	-0.397	0.989	-0.231	-0.146	1.000		
Na^+	-0.482	0.293	-0.612	-0.188	0.062	0.170	0.087	-0.565	-0.434	0.517	-0.653	-0.113	0.083	0.829	-0.496	0.109	1.000	
K^+	-0.991	-0.171	0.172	-0.936	-0.532	-0.175	0.561	-0.859	0.621	0.553	-0.924	-0.951	0.187	0.641	0.522	0.327	0.406	1.000

All parameters are in mg/L with the exception of Turbidity (NTU) temperature (^0C), pH and EC (µS/cm)

Table 7: Pearson's Correlation Coefficient Matrix of Physicochemical Parameters (Mean) of Old Tin Mine Pond Water Dry Season Jos- South

	Tub.	Temp	BOD	COD	DO	pH	EC	TSS	TA	TH	Cl^-	NO_3^-	SO_4^{2-}	TPO_4^{3-}	F^-	NH_4^+	Na^+	K^+
Tub.	1.000																	
Temp	0.022	1.000																
BOD	-0.313	0.322	1.000															
COD	-0.522	0.277	0.973	1.000														
DO	-0.692	-0.144	0.807	0.894	1.000													
pH	0.431	-0.885	-0.532	-0.577	-0.266	1.000												
EC	-0.245	0.108	-0.744	-0.611	-0.528	-0.097	1.000											
TSS	0.903	0.135	0.125	-0.106	-0.345	0.239	-0.608	1.000										
TA	0.134	0.349	0.985	0.996	0.849	-0.615	-0.626	-0.039	1.000									
TH	0.134	-0.825	-0.799	-0.746	-0.372	0.862	0.396	-0.200	-0.801	1.000								
Cl^-	-0.871	-0.050	0.699	0.839	0.955	-0.405	-0.261	-0.587	0.788	-0.357	1.000							
NO_3^-	-0.714	-0.488	0.529	0.652	0.922	0.054	-0.377	-0.484	0.579	0.014	0.890	1.000						
SO_4^{2-}	-0.908	-0.080	-0.106	0.123	0.341	-0.291	0.616	-0.998	0.061	0.154	0.589	0.461	1.000					
TPO_4^{3-}	0.665	-0.731	-0.474	-0.582	-0.382	0.957	-0.225	0.505	-0.595	0.720	-0.568	-0.136	-0.550	1.000				
F^-	0.820	-0.100	-0.795	-0.912	-0.950	0.524	0.325	0.494	-0.875	0.513	-0.985	-0.819	-0.504	0.647	1.000			
NH_4^+	0.895	0.385	0.068	-0.157	-0.485	0.031	-0.424	0.956	-0.075	-0.321	-0.666	-0.679	-0.941	0.318	0.547	1.000		
Na^+	0.401	0.625	0.681	0.512	0.124	-0.457	-0.681	0.714	0.586	-0.825	-0.037	-0.227	-0.682	-0.209	-0.124	0.757	1.000	
K^+	0.402	-0.593	0.291	0.169	0.289	0.633	-0.831	0.580	0.157	0.178	0.006	0.354	-0.616	0.701	0.014	0.317	0.257	1.000

All parameters are in mg/L with the exception of Turbidity (NTU) temperature (^0C), pH and EC (µS/cm)

Table 8: Pearson's Correlation Coefficient Matrix of Physicochemical Parameters (Mean) of Old Tin Mine Pond Water Rainy Season

	Tub.	Temp	BOD	COD	DO	Ph	EC	TSS	TA	TH	Cl^-	NO_3^-	SO_4^{2-}	TPO_4^{3-}	F^-	NH_4^+	Na^+	K^+
Tub.	1.000																	
Temp	0.345	1.000																
BOD	-0.867	-0.380	1.000															
COD	-0.550	0.479	0.629	1.000														
DO	-0.538	0.505	0.202	0.641	1.000													
pH	0.821	0.599	-0.515	-0.011	-0.384	1.000												
EC	-0.735	0.339	0.705	0.962	0.757	-0.276	1.000											
TSS	0.211	-0.478	-0.516	-0.875	-0.225	-0.384	-0.720	1.000										
TA	0.284	-0.692	-0.399	-0.956	-0.584	-0.261	-0.855	0.913	1.000									
TH	-0.601	-0.050	0.890	0.790	0.126	-0.077	0.742	-0.836	-0.670	1.000								
Cl^-	-0.921	-0.150	0.953	0.784	0.486	-0.538	0.876	-0.569	-0.571	0.853	1.000							
NO_3^-	-0.080	0.887	0.088	0.829	0.675	0.358	0.726	-0.752	-0.939	0.374	0.320	1.000						
SO_4^{2-}	-0.345	0.313	-0.142	0.160	0.860	-0.506	0.339	0.297	-0.109	-0.356	0.117	0.305	1.000					
TPO_4^{3-}	-0.986	-0.356	0.938	0.603	0.450	-0.738	0.755	-0.329	-0.343	0.720	0.963	0.098	0.195	1.000				
F^-	-0.123	0.385	-0.365	0.007	0.763	-0.355	0.157	0.397	-0.013	-0.540	-0.110	0.269	0.973	-0.034	1.000			
NH_4^+	0.721	-0.382	-0.485	-0.802	-0.952	0.444	-0.912	0.415	0.694	-0.414	-0.726	-0.678	-0.695	-0.672	-0.542	1.000		
Na^+	0.533	0.794	-0.784	-0.067	0.414	0.406	-0.117	0.155	-0.146	-0.635	-0.562	0.477	0.558	-0.627	0.708	-0.143	1.000	
K^+	-0.158	-0.850	-0.038	-0.738	-0.331	-0.648	-0.545	0.860	0.901	-0.443	-0.180	-0.919	0.080	0.086	0.081	0.371	-0.360	1.000

All parameters are in mg/L with the exception of Turbidity (NTU) temperature (^0C), pH and EC (µS/cm)

DISCUSSION

TURBIDITY

All the samples from the studied mined ponds recorded mean values that were above the FAO, (1985) standards for irrigation water. However, higher values may indicate the presence of particulate matter such as clay/silt, decomposed organic matter and other forms of pollutants that reduce the transparency of the water contributed by illegal mining currently taking place in the area by local miners, as such; treatment is necessary to get desired result (Murhekar, 2011). Activities such as; the use of excavators, earth moving equipment, shovels and pick axe in the excavation of tin ores could enhance the dissolution and or washing of silt into the mining ponds, these are prone in Barkin – Ladi compared to other study areas because of the location of the pond which is very close to mechanical workshops and block industries. Thus, impurities from runoff into the various open ponds contributes to the elevated level of turbidity (Mafuyai *et al.,* 2019b). The higher levels of turbidity reported along the mining ponds could largely be due to the activities of small-scale miners as reported (Yidana *et al.,* 2012). Irrigating vegetables with turbid water could affect the quality of the vegetables produced, since bacteria and viruses could attach and migrate to the vegetables through solid particles in the water (Jeong *et al.,* 2016). Also, high turbidity levels in irrigation water affects the aesthetic quality of the vegetables produced as reported by some farmers from the study area (Mafuyai *et al.,* 2019b).

TEMPERATURE

The high temperature 25.1 ^{0}C and 29.3 ^{0}C in dry and rainy seasons obtained in Jos South may be unconnected to high solar radiation in rainy seasons, absence of vegetative cover around the ponds and heating from industries and households around the ponds. The temperatures obtained during the rainy season were higher than those of dry season as recorded in this study. All values are within the FAO/WHO, (2007) standards. However, the values of temperature reported in this work are in agreement with studies on the Seasonal physicochemical characteristics of Nagani/Wubang mined pond water in Langtang North Local Government Area of Plateau state (Gongden and Lohdip 2015).

pH

The pH is positively correlated with BOD and COD, and negatively correlated with DO in both dry – and – rainy season at ($p < 0.05$). The slight acidity of the mining pond water could be due to the addition of excess mineral from the geologic soil from the mining area activities on Land use/Land covering Bukuru, Plateau State (Jiya and Musa, 2012). This observation may be due to the presence of algae and other aquatic plants on the surface of the reservoir. Algal respiration leads to the release of carbon dioxide which reacts with the water to produce carbonic acid, which result in an increased acidity (Yidana *et al.*, 2012). Similarly, microbial utilization of dissolved oxygen releases carbon dioxide which reacts with water to produce carbonic acid resulting in a lower pH. The greatest hazard associated with an abnormal pH in irrigation water is its impact on the equipment used for irrigation where it is not correctly calibrated with the required buffer (Jeong *et al.*, 2016). Furthermore, crop foliage is damaged when it gets wet by water with abnormal pH, this could result in reduction in yield and also depreciation of the quality of marketable material (crops). The slight acidity of the mine pond water can affect crops when directly in contact with the leave and on the one hand, by a release of exchangeable cations during a process of an organic material mineralization brought by wastewater

(Hussain *et al.,* 2010; Kiziloglu *et al.,* 2008). The pH obtained in this work agrees with the literatures reported by Anim-Gyampo *et al.* 2012 and Bao *et al.* 2014.

ELECTRICAL CONDUCTIVITY (EC)

The mean values of mining pond water of the two seasons did not show much elevated EC in the years, but the values were higher in Jos – South during both dry and rainy season than the other sites (220 and 210 μScm^{-1}), respectively. Several studies showed significant variation in the electrical conductivity compared to the values obtained in this work (Kangpe *et al.* 2014; Osuocha *et al.* 2016; Mahmood and Malik, 2014). The different EC recorded by the authors might be due the parent rock type which showed lower EC values in Nagani/Wubang dam water in north central Nigeria (Gongden and Lohdip, 2015). Higher EC values in the water was due to the illegal mining taking place around the abandoned ponds supported by the study of Artisanal and small-scale miners in solid minerals industry (Davou and Dung - Gwom, 2008). Also, the higher EC in the rainy season may be due washing of ashes from bush burning that empty water into the ponds. However, the values obtained in this work were far lower compared with 723 $\mu S\ cm^{-1}$ reported in Haipang, Plateau State (Daniel *et al.,* 2014). From the EC value it is quite clear that both sources of irrigation water will not pose any soil salinity problem in the future and the EC values are within the safe limit prescribed standard by FAO/WHO (2007). The values of EC obtained from the sites corroborated with report of Kampani River in Wase, Plateau State (Lawal *et al.,* 2014).

TOTAL SUSPENDED SOLIDS (TSS)

The mean of the suspended solids results indicates that there is a high variation of TSS values in the two seasons as they differ greatly. However, the TSS values observed during the rainy season were within the limit of FAO/WHO (2007) standard for irrigation water, while the values obtained in dry season were above the recommended values. This is because mining by artisanal miners is high during the dry season which produces a lot soil debris (Davou and Dung-Gwom, 2008). The TSS values of mining pond water were higher in comparison with some of the ponds water reported in Haipang (Daniel *et al.,* 2014). In most of the municipal wastewater the TSS values ranges from 10 to 20 mg/L and values below 100 mg/L pose no restriction to irrigation use. The higher values obtained in this work can pose threat to irrigation pending on the type of crops grown.

TOTAL DISSOLVED SOLIDS (TDS)

The mean TDS values for the tin mining pond water in the various studies sites were in the range of 219 - 288 mg/L in dry season, and 267 – 414 mg/L in rainy season. The values indicate that the water TDS is influenced by seasonal variations, this may be due to higher rate of evaporation in dry season and less influx and runoff water during dry and rainy season. All the TDS values, obtained from this studyare well within the safe limit of prescribed irrigation water quality standards (FAO, 1985). The classification of the water on the basis of TDS indicates that the mining water is good for irrigation when other required parameters satisfy the requirements.

BIOCHEMICAL OXYGEN DEMAND (BOD)

Biochemical oxygen demand (BOD) represents the quantity of oxygen required by bacteria and other microorganisms to degrade and transformation of organic matter present in wastewater under aerobic conditions. From result obtained it is observed that the highest BOD was found ranged from 7.37 – 29.3 mg/L in the three study in both seasons with the lowest in Bokkos. These values obtained for BOD are higher than the prescribed standard 2mg-O_2/L for irrigation water. The high level of BOD in the mining pond water also indicated the presence of excessive number of bacteria in the water, which consumed the dissolved oxygen (WHO/FAO, 2007; FEPA, 1991).

CHEMICAL OXYGEN DEMAND (COD)

The chemical oxygen demand (COD) is a measure of the oxygen equivalent to that portion of organic matter present in the wastewater sample that is susceptible to oxidation by oxidizing agents (i.e., potassium dichromate). It is a quick estimation of organic loading in wastewater. The higher COD value observed in Jos – South in rainy season, this might be due to the anthropogenic activities and dilution with runoff discharges from sewage water. But the COD values of mine pond water are below the safe limit as prescribed by WHO, (1993), though lower compared to 964 mg/L reported on wastewater used in irrigation (Alghobar and Suresh, 2017).

DISSOLVED OXYGEN (DO)

DO is an important water quality parameter for most chemical and biological processes in water bodies and is essential for all aquatic life. As BOD was very much higher in the mining pond water, the dissolved oxygen (DO) was very much lower than the prescribed irrigation water quality standard. This indicates that the water may be toxic for aquatic life in that area and it might cause many diseases in crops. The values DO show a positive correlation with the BOD in dry seasons. This indicates that the water needs treatment to support aquatic life (Bamniya *et al.,* 2010).

TOTAL ALKALINITY

Alkalinity is a measure of the acid buffering capacity of water. It is the sum of the amounts of bicarbonates (HCO_3^-), carbonates (CO_3^{2-}) and hydroxide (OH^-) in water. The high value in Jos – South in both seasons may be attributed to drains and washings from industries and households while in the ponds there are no houses close this may be due to lack of diluting water (Mafuyai *et al.,* 2019b). The mean values other sites showed almost similar alkalinity with in the mining pond water in during the seasons. The alkalinities of irrigation water obtained are within the safe limit of FAO, (1985) and there is no need to calculate the residual sodium carbonate (RSC) and permeability index (PI) of such irrigation water.

TOTAL HARDNESS (TH)

The presence of multivalent cations, most notably calcium and magnesium ions, is referred to as water hardness. Both sources of water have considerable amount of hardness, which is due to addition of ions either by leaching from rocks in case of groundwater or washing of rocks and from mining exploration in case of mining pond water. The values of hardness in irrigation water obtained in this study follow similar trend with the values reported in Kampani mine River, Nigeria (Lawal *et al.,* 2014) and 317.3 mg/L in Haipang, Barkin- Ladi (Daniel *et al.,* 2014). The high values in tin mining pond water in this study is thus, lower compared to the prescribed 500 mg/L irrigation water standard value (FAO, 1985).

CHLORIDE (CL^-)

The mean values Cl^- recorded in this work are higher ranging from 11.3 – 43.4 mg/L in both sampled sites of the studies, but higher than the reported value 12.19 mg/L of Kampani mine dam in Wase, Plateau, Nigeria (Lawal *et al.*, 2014) and however, lower compared to the result 98.7 mg/L obtained at Haipang Barkin-Ladi mining pond (Daniel *et al.*, 2014) and 124.4 mg/L reported in Ishiagu, Ebonyi State (Osuocha *et al.*, 2016). The chloride concentrations of irrigation water sources are within the prescribed limit (FAO, 1985). All the mining pond water sources in terms chloride quality are good and can be regarded for used in irrigation along other satisfactory parameters without any restriction.

NITRATE-NITROGEN (NO_3^- – N)

All the concentrations of nitrate recorded during the entire study period fell within the FAO permissible limit of 10 mg/L for irrigation water use, exception of the mining pond water in Barkin Ladi (11.2 mg/L) in dry season. High concentration of nitrate in irrigation water can also cause excessive vegetative growth, poor quality fruiting and delay maturity in crops (Gongden and Lohdip, 2015). The presence of nitrate in the water may be due to surface-runs or leaching from the soils of surrounding farms which indicates the use of nitrogen fertilizer by farmers. This was confirmed by the farmers that they use fertilizer in the areas for crop production. Furthermore, indiscriminate defaecation around water banks and by miners/farmers might also influence the concentration of nitrogen in the water which may lead to the high BOD in the mining pond water (Mafuyai *et al.*, 2019b).

SULPHATE (SO_4^{2-})

The high sulphate in Jos - South may be due weathering of rocks or leaching from rocks that contain calcium sulphate, magnesium sulphate and/or sodium sulphate (Okoffo, 2016). Other possible sources could be anthropogenic activities, most likely, industrial, farming and prolonged illegal mining at the areas. All the mining pond water sources in the study areas are far lower than the prescribed standards limit (FAO, 1985). The result of this findings agrees with values ranged 3.30 – 73.9 mg/L reported (Bharose *et al.*, 2013), but was however, lower compared with 280 – 300mg/L reported in Mista Ali Bassa, Plateau State (Kangpe *et al.*, 2014), these might have been due the topography and the mine pond far from water loading or the use of sulphate fertilizers close to the ponds (UNEP, 2005).

TOTAL PHOSPHATE (PO_4^{3-})

The phosphate is a normal component in surface water which is derived from natural processes but its quantity increases with input of effluents from domestic and industrial sources. Agricultural sector also contributes phosphate residue through runoff water. Irrigation with phosphate enriched water leads to increase the fertility of the soil. The values obtained in this work are far above the permissible limit of 2.0 mg/L for irrigation water (FAO, 1985). Water enriched with phosphorus could enhance the rapid growth of algae and other aquatic plants. The presence of phosphates in the water at all the sites might be as a result of the use of organophosphate pesticides and phosphate fertilizers by farmers that leached into the ponds (Davou and Dung-Gwom, 2008).

FLUORIDE (F^-)

The geogenic sources are responsible for the fluoride (F–) in the irrigation water. The values of mine pond water in dry season were very closer though, in rainy season fluoride values are higher, this might be due to high evaporation and washing of dumps and tailings into mining ponds. The mean value obtained in this study is lower compared to the prescribed safe limit of 1.5 mg/L (WHO, 2008). The higher due to high evaporation and diminishing flow of the mining pond water channel.

AMMONIUM (NH_4^+)

Comparing the results NH_4^- obtained with previous studies in the same area by Henry the changes (increases) in NH_4^+ concentrations in the tin mine pond water, probably indicate that the NH_4^+ is derived from an anthropogenic source and can also be attributed to contamination since some ponds were abandoned and refuse are dumped into some of this ponds by water run-off (Mafuyai *et al.,* 2019b).

SODIUM (NA^+)

The concentration of Na^+ obtained in this study is higher than the value of 1.45 – 5.26 mg/L (Hussain *et al.,* 2010) and lower compared with literature value 48.0 mg/L reported in Mysore City Karnataka (Low *et al.,* 2016) and the mean value of 34.2 mg/L from Okpauku River in Nigeria (Akpan-Idiok *et al.,* 2012). The causes of high Na^+ content in mining pond water during rainy season may be due to the input from burnt ashes washed and emptied into the ponds (Mafuyai *et al*., 2019b). The concentrations of sodium in the mining pond water for the entire study period were far below the FAO permissible limits of 920 mg/L for irrigation water (FAO, 1985).

POTASSIUM (K^+)

The mean concentration of potassium in mining pond water does not showed variation with seasons and notably it is also found that the potassium level is remarkably lower dry season are lower compared to FAO/WHO (2007) limits of 2 mg/L irrigation water standard, while those obtained during rainy seasons has higher K^+ concentrations than the FAO, recommended limit. The concentration of K^+ in tin mining pond water shows a positive correlation with Cl^- and TSS in dry season and negative correlation EC and COD. The high concentration may be due to natural occurrence in water of K^+ through weathering of rocks and anthropogenic sources.

CORRELATION ANALYSIS

Correlation of physico-chemical parameters in Bokkos dry and rainy seasons are respectively in (Table 3 and 4), turbidity shows positive correlation with TSS, NO_3^- and Hardness in dry season while rainy season turbidity was positively correlated with COD, DO, Cl- and negatively correlated with TSS (Table 4). BOD was positively correlated with COD in dry and negatively with DO in rainy season, while in dry season COD was negatively correlated DO and positively with DO in rainy season. The pH of the tin mining pond was positively correlated with the EC in both seasons, thus the EC positively correlated with SO_4^{2-}, NH_4^+ in both dry and rainy seasons. SO_4^{2-} and NO_3^- were positively correlated with PO_4^{3-} and SO_4^{2-} respectively, while the TSS was observed to correlate positively with NO_3^- . The total alkalinity was positively correlated with Na+ and Hardness in both dry and rainy seasons in Bokkos.

In Barkin-Ladi (Table 5 and 6), turbidity correlated positively with EC and pH In dry season, and negatively with COD, NO_3^-, while BOD correlated positively with DO. The COD in both rainy and dry season correlated positively with Cl^-. The EC correlated positively TSS, SO_4^{2-} in both two seasons. The tin mining pond water TSS shows positive correlation NO_3^- Cl^- in both dry and rainy season. The total hardness was positively correlated with TPO_4^{3-} in dry season and SO_4^{2-}, NH_4+ in rainy seasons, while PO_4^{3-} was positively correlated F^- and SO_4^{2-}, NH_4^+ in both seasons see (Table 6).

In Jos-South (Table 7 and 8), the turbidity correlated positively with TSS and pH in dry and rainy seasons, while the BOD correlated positively with COD, DO and total hardness in dry season. The COD correlated positively with DO, total alkalinity Cl^- in dry season and EC rainy season. The DO correlated positively with NO_3^- and EC in dry and rainy season. The pH was positively correlated PO_4^{3-} Cl^-, while the TSS was positively correlated with NH_4^+, Na^+ and negatively correlated with SO_4^{2-} in dry season and rainy positively correlated with alkalinity. The Cl^- was positively correlated with NO_3^- and negatively correlated with F^- in dry season, while in rainy season NH_4^+ was positively correlated with Na^+. Looking at the correlation coefficients of the physico -chemical parameters is a clear indication of the contribution of these ionic components to the overall mineralization of the water. The positive correlation exhibited among the parameters examined is a clear indication of a common source of ionic contribution.

The mean differences of the two irrigation water sources are calculated with the help of student t-test. The mean difference of control parameters in dry- and –rainy season showed significant ($p < 0.05$) differences ($t = 3.182$) between turbidity, temperature, total hardness, total alkalinity, total dissolved solids, dissolved oxygen biological oxygen demand, chemical oxygen demand, ammonia, chloride and fluoride, except pH, Na+, at both seasons in Bokkos and NO_3^- in dry season, while pH, EC and pH, NO_3^-, Na^+ in Barkin - Ladi and Jos – South, respectively. Although values of Na^+, K^+ and TSS, TPO_4- in dry – and- seasons, respectively were not significant, it can be inferred that tin mining pond water and seasonal changes have significant contribution over the variability of the said parameters.

CONCLUSION

Evaluation of seasonal physico-chemical data from the study area have provided information on the quality of tin mine pond water, sources of pollution and their suitability for consumption and irrigation purposes. Some of the physico-chemical parameters of all sampled water fell within FAO/WHO guideline values for irrigation water with the exception of turbidity, dissolved oxygen, total alkalinity, biological oxygen demand, total phosphate and potassium which were higher than recommended limits in both dry and rainy seasons. The total suspended solids were also higher in dry season in mine pond water. The positive correlation exhibited among the parameters examined is a clear indication of a similar source of pollution contribution. This study is very significance as it has revealed that some of physicochemical qualities of mining pond water used for irrigation are abnormal and may likely be detrimental to irrigated crops and humans. Therefore, the mining pond water used for irrigation should be closely monitored by the relevant authorities of government to ensure that the over usage of the does not cause toxicity to the irrigated crops.

DECLARATION

I on behalf of the coauthors of the work, hereby declare that this manuscript has not been published in any scientific journal or submitted for review and publication.

ACKNOWLEDGEMENT

The authors would like to acknowledge Prof. I. S. Eneji, of Department Chemistry University of Agriculture Makurdi, Benue State, Bala Ajik, Department Science Laboratory Technology University of Jos, Plateau State for drawing the maps of the study site and my Wife Mrs. Victoria Godwin Mafuyai of University of Jos Health Services, for their various contributions in bringing this article to completion for publication, thank you and God bless.

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